

# Climate Change – What Should Southern California Prepare for?

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Southern California's climate is changing and will continue to change over the next several decades, along with other regions of the earth. These changes are the results of the growing accumulation of greenhouse gases in the atmosphere. Carbon dioxide and other greenhouse gases have already risen substantially above natural levels, and will rise more as their emissions continue. These human-produced gases are powerful absorbers of the radiation emitted from the earth's surface, and the extra amount of energy that they radiate back to the surface then warms, additionally, the earth. Measured emissions of CO<sub>2</sub> over the period of 2000-2007 are much higher than in the previous decade, and even exceed those sketched out for the worst-case scenario that has been considered by the Intergovernmental Panel on Climate Change (IPCC). Fossil fuels dominate our energy consumption – not only in the United States but increasingly in China, India and other expanding economies. And the CO<sub>2</sub> that fossil fuel use produces, along with other important greenhouse gases, persist far above natural levels for decades after they are loaded into the atmosphere. Thus it is quite likely that by the end of the 21st Century the atmospheric CO<sub>2</sub> concentration will double, over its pre-industrial level. If global society continues to rely mainly upon fossil fuel energy sources, the CO<sub>2</sub> concentration could triple.

It is probably not an exaggeration to say that climate change is one of the greatest challenges that society has ever confronted. To prepare for and to reduce these problems requires us to make decisions based on projections of conditions that have never been experienced by humans. Increasingly,

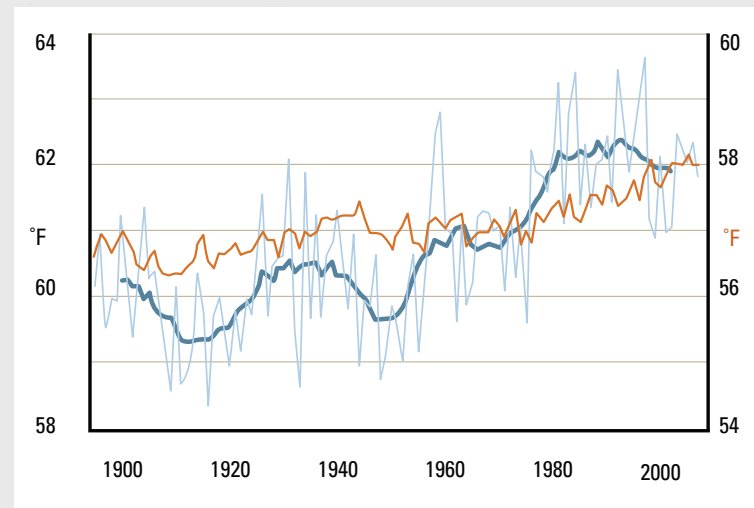
in addition to issues surrounding shorter term climate impacts such as occur during large El Niño events, we in the climate community are scrambling to provide scenarios that will shed light on risks of climate changes. We know, with great certainty, that the consequences will grow the longer greenhouse gases are allowed to accumulate at full throttle. Greenhouse gases are emitted globally so that reductions across an international network are needed. However, to achieve meaningful reductions will require actions, beginning right now, from individual parties, and the impacts expected are severe enough that the State of California has stepped forward. In an unprecedented process set forth by the California legislature and Governor Schwarzenegger's administration, the State has instituted measures to reduce emissions as well as to monitor and plan for changes in climate and sea levels.

Two pieces of evidence point toward substantial future climate change. First, early signs of a warming earth are appearing at an increasing rate. If the only warming we had observed was confined to a limited region such as western North America, the warming might simply be a temporary natural climate fluctuation and we could expect, within a few years, a transition back to a cooler regime. But, in fact, there is a global signature – surface air temperature here in California has risen about 1° F over the last 100 years (Figure 1) similar to the warming of average temperature from a global array of thermometer records. In recent decades, warming has become more acute, and along with it has come a set of other changes, including more rain/less snow and earlier snowmelts in western mountains and advances in spring plant blooms. Although the warming is still modest, the levels of seasonal and annual temperatures are beginning to extend above the highest temperatures observed historically. Furthermore, the pace of change is exceptionally fast, when compared to long records that have been constructed from proxy records of climate such as from tree rings, sediments and coral

records, and this warming is taking place over a broad global domain. In fact, the warming, along with other changes, has a “fingerprint” that is in line with the pattern of changes that are predicted by model and theoretical reasoning when greenhouse gas concentrations are increased. Thus, it is quite certain that we (humans) have caused this warming.

Figure 1

### South Coast Annual Average Temperature



Light blue curve shows historical annual surface temperature (left scale), averaged across several stations recording temperature in the “South Coast” region, from Western Regional Climate Center Climate Tracker <http://www.wrcc.dri.edu/monitor/cal-mon/california-climate-monitor.html>.

Dark blue curve is 11 year smoothed (running mean, showing over 1°F increase). For comparison, the orange curve (right scale) shows warming of global land and ocean surface temperature from Smith and Reynolds. <http://www.ncdc.noaa.gov/oa/climate/research/anomalies/anomalies.html>.

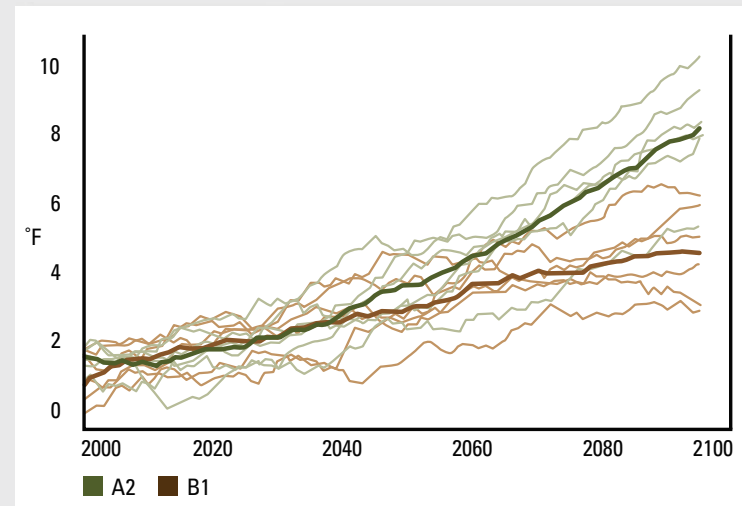
Second, looking forward, the fact that humans have caused the warming in recent years means that continued, collective human impacts will lead to even greater changes. Various scenarios for increased greenhouse gas concentrations have been explored using computer-run numerical models that have been devised to simulate the dynamics of the climate system. These models provide a way to study the changes in climate that may occur over the next several decades. A comprehensive global scale evaluation from several global climate models (GCMs) was presented in the recent 2007 IPCC Fourth Assessment. The information from these climate models is resolved at a pretty coarse scale, but it can be combined with the structural information that we have from observed historical temperature and other data over California. We use this information to “downscale” the climate model changes to project changes onto the Southern California landscape and thus infer how climate change may evolve over our region, which is in many ways unique from the rest of the United States.

How much and how fast will Southern California’s climate warm? The models suggest that by 2050, the amount of warming is likely to exceed the 1°F we have already experienced, perhaps by yet another 1-2°F, and by 2100 it will likely reach 4°F above current levels. Greater warming, possibly as much as 10°F, could occur if greenhouse gas emissions continue at a high rate (Figure 2). The six GCMs, run under two very different emissions scenarios are ones used in the 2008 California Climate Change Scenarios assessment. Because we are not able to predict how regulations, technology and economic activity will develop in future decades, several differing scenarios describing the trajectory of future greenhouse gas emissions are typically explored in these evaluations, and it is not possible to assign odds to different emissions scenarios. Consequently, the climate projections should be viewed as a set of possible outcomes, none of which would qualify as a specific prediction.

Climate Change and the Future of Southern California

Figure 2

### Annual Temperature Projected Change, Los Angeles



Projected change in annual mean temperature, Los Angeles region, from six Global Climate Models (GCMs), for A2 (green) and B1 (brown) greenhouse gas (GHG) emission scenarios. Light green curves and brown curves are individual A2 and B1 simulations, respectively. The six GCMs and the two emissions scenarios are ones used in the 2008 California Climate Change Scenarios assessment. The A2 and B1 scenarios represent two plausible, but very different trajectories of the world economy, society, and energy system, and imply divergent paths of future anthropogenic GHG emissions, with projected emissions in A2 being substantially higher than for B1. Temperature changes are relative to 1961-1990 annual average temperature for the grid point nearest Los Angeles from each of the GCMs, respectively.

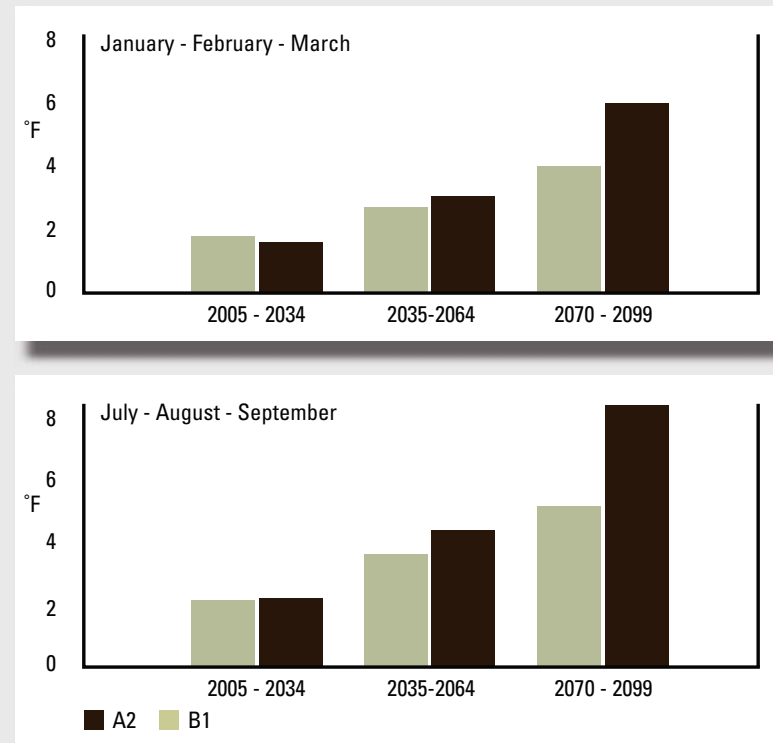
What we can be very certain of, however, is that the rate of warming will increase substantially over the rates we have seen in recent decades. Climate model projections based on lower end emission trajectories indicate that, by 2100, temperature increases will likely exceed 3°F.

In contrast, by 2100, the upper-warming end of the climate models and greenhouse gas emission scenarios actually produce warming that is greater than 7°F. This degree of change may seem trivial in comparison to daily and seasonal temperature fluctuations, but it is enormous when we consider that they represent the shifts in multi-year averages. Importantly, even if greenhouse gas emissions were to be cut back today to pre-industrial levels, there is still about 1°F more warming in store from changes we have already set in motion. The earth will continue to warm because it is still adjusting to the increased levels of greenhouse gases that we have already loaded into the atmosphere. And, the use of the 2100 endpoint in the model simulations is arbitrary – in a number of scenarios, the warming and associated climate change would continue long after that.

One aspect of climate change that we are wrestling to understand is how the amount of warming may differ from season to season and how it will play out over the California landscape. Several of the recent climate simulations suggest that summer temperatures will increase more than those in winter (Figure 3). And, the warming projected in the models varies as we cross California. It is troublesome that several of the models project summer warming to strengthen in the interior just beyond the immediate Southern California coastal zone (Figure 4). This intensification could have severe impacts upon our public health and our supply of water and energy. And, a summer-amplified warming could be a harsh challenge to Southern California wildlife and ecosystems, which in the present day are said to be amongst the most diverse of all regions on earth.

Figure 3

### Los Angeles Temperature Change From 1961 - 1990



Projected surface air temperature changes in winter (January through March, upper) and summer (July through September, lower) show greater increases in summer. These are averages of data from six GCMs for higher (A2, brown) and lower (B1, green) GHG emissions scenarios. Temperature changes are relative to 1961-1990 average temperature for the grid point nearest Los Angeles from each of the GCMs, respectively.



And, it is not only our average temperatures that will warm – the models indicate that extreme temperatures will also rise. The Southern California climate will continue to contain weather and short period climate fluctuations superimposed upon longer term trends. Historically, most of our heat waves have occurred in July and August, but as climate warming takes hold, these events will likely begin to appear earlier in the season and could continue through the Fall period, while summer events become more frequent and more intense. Model simulations suggest that California cities will see a great increase in hot days, as represented for Los Angeles by one GCM simulation, the A2 simulation of the Geophysical Fluid Dynamics Laboratory (GFDL) of the National Oceanic and Atmospheric Administration (NOAA) in (Figure 5). By the end of the century, if greenhouse gas emissions continue along the higher trajectory, heat wave days could increase by fourfold or more. And, within a given heat wave, there is an increasing tendency for multiple hot days in succession – heat waves last longer. Especially important may be the lack of nighttime cooling that has characterized recent heat waves in California, and the projection that the occurrence of events having durations of 5 days or longer will become much more prevalent by the last decades of the 21st Century, putting huge strains on our health and utility infrastructure.

Figure 4. July maximum temperature throughout Southern California from the A2 simulation of GFDL global climate model (lower panel) is projected to warm considerably, especially over inland regions.

Upper and lower panels compare historical (1961-1990) version of GFDL simulation with mid-21st Century (2035-2064) simulation.

In these maps, the GFDL model temperatures have been “downscaled” from the coarse 150km GCM scale to a 1km spatial matrix covering the California landscape.

Figure 4

### Maximum Temperature During July

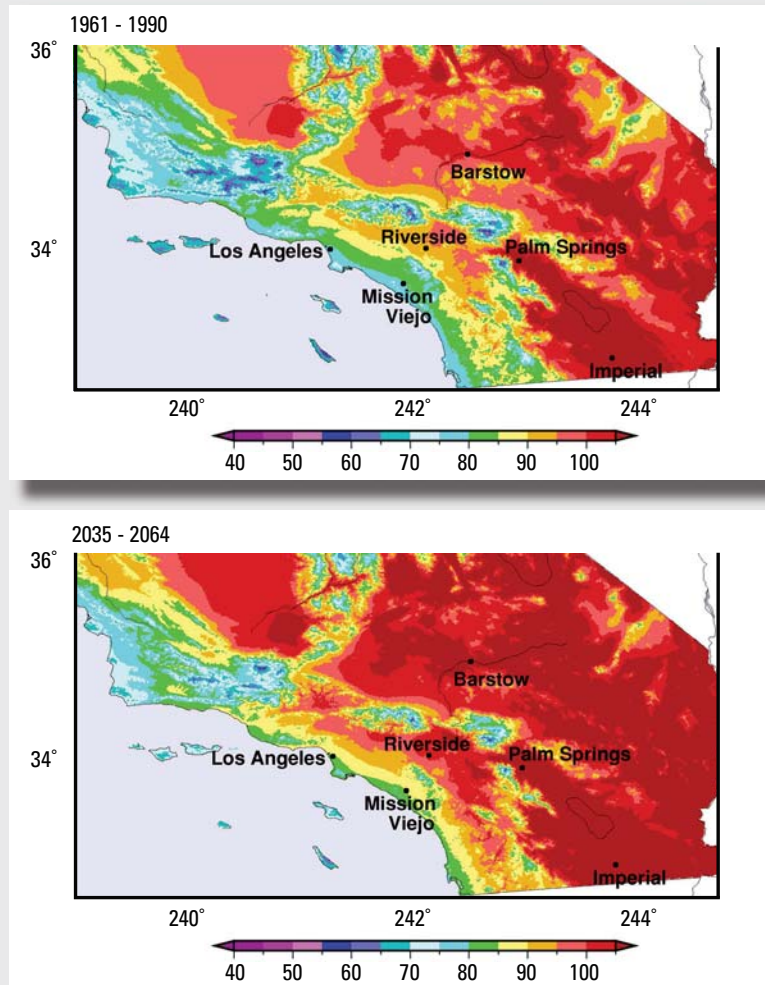
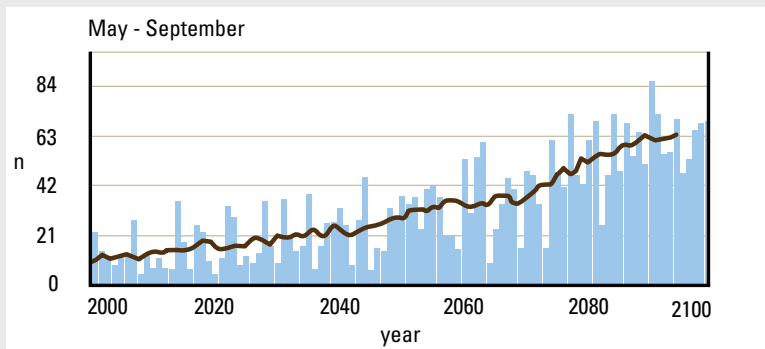


Figure 5

### Los Angeles Number of Extremely Hot Days



Projected number of heat wave days in Los Angeles from the GFDL GCM simulation, under the A2 GHG emissions scenario. In this case, a heat wave is any day exceeding 81°F, the 95th percentile of daytime temperature in Los Angeles during May through September from 1961-1990.

Southern California has one of the most urbanized and most productive economies in the United States. But along with this comes the misfortune of having very high air pollution loadings. The pollution problem in Los Angeles is set up by the temperature inversions from subsiding air masses around the North Pacific high pressure center, and is complicated by the mountains to the north and east of the Los Angeles basin that further trap pollutants. Additionally, Southern California's air pollution is aggravated by ozone buildup, especially when warm sunny days with stagnant atmospheric conditions produce greater chances for photochemical reactions affecting trapped emissions. Ozone and particulate matter are often considered the most critical in adversely affecting human health, and have been implicated as being particularly harmful to children's health. Climate model projections

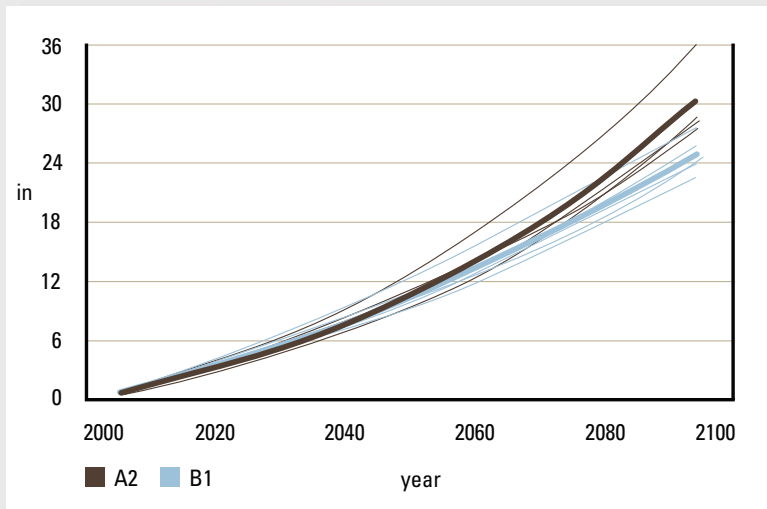
of future temperature rise combined with the historical ozone trends indicate that the number of days with high ozone conditions will markedly increase. Warmer future temperatures might require the implementation of additional emissions controls in order to offset this climate-driven increase.

Compounding California's climate problems is our coastal setting. Climate warming, in causing thermal expansion within the global oceans and in melting glaciers and large ice stockpiles in Greenland and Antarctica, will likely accelerate sea level rise, probably multiplying the rates that we have observed over the last century. This would not only increase the risk of erosion of coastal structures and shrink our beaches, but also will increase the chances of salt water intruding into our fresh water systems. Southern California is familiar with rising sea level, which has been occurring before and during the period of our modern development. Sea level measured at tide gauges along the California coast rose by a total of about 7 inches over the last century – similar to rises estimated for the global ocean. But as temperatures near the surface of the earth warm, sea levels will rise even more. By 2050, relative to its 2000 level, sea level seems likely to rise by another foot. Estimates of future sea level rise have not converged to a well defined rate, and some recent mainstream estimates are significantly larger than has been publicized by the IPCC in their Fourth Climate Assessment, released in 2007. Estimates of sea level rise by the end of the century have upper ranges of more than 4 feet (Figure 6). A major vulnerability in California's water systems is the Sacramento/San Joaquin Delta, through which much of the State's freshwater passes on its way to meet water demands that span the entire state south of Sacramento. As sea level rises, it will also elevate shorter term extremes of tides, storm surge and waves, so there will be an increased rate of extreme high sea level events. Add a foot or more to sea levels in the long run, and when

large storm-generated waves happen to coincide with high tides, as during major storms in the 1982-83 El Niño winter, we have the recipe for severe flooding and rapid coastal erosion. And, as decades proceed, heightened sea level events will persist for more hours, which would impose a greater threat of coastal erosion and other damage, especially to the fragile levees in the Delta.

Figure 6

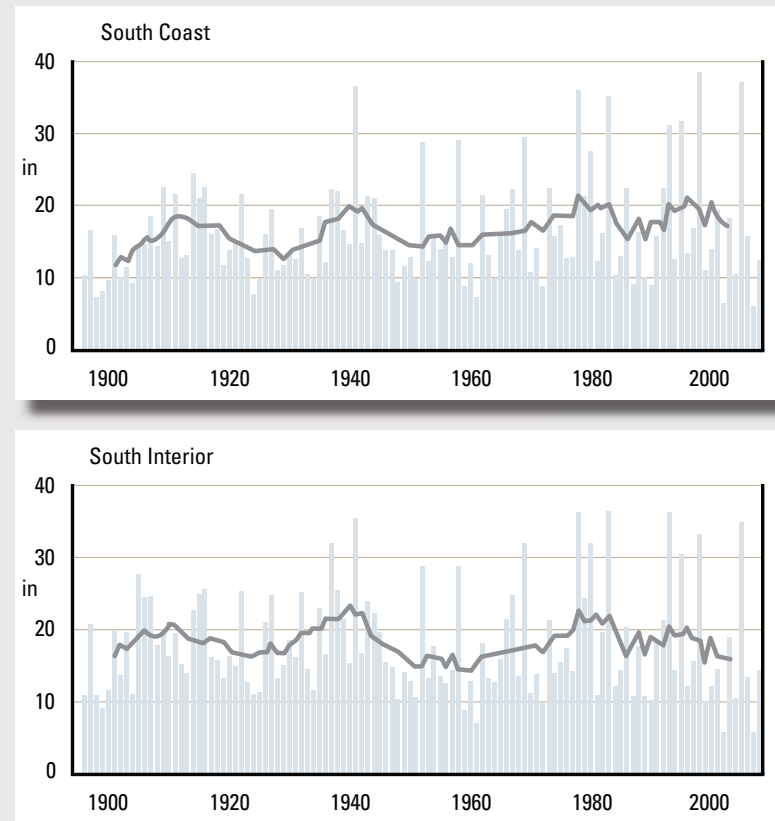
### Projected Sea Level Rise for Southern California Coastline



Sea level for Southern California coast under projected global warming, from A2 (brown) and B1 (blue) GHG emissions scenarios simulated by six different GCMs. Sea level changes have been estimated using the method of Rahmstorf (2007). Light lines are the six A2 and the six B1 simulations and bold lines are mean of the A2 and B1 simulations.

Figure 7

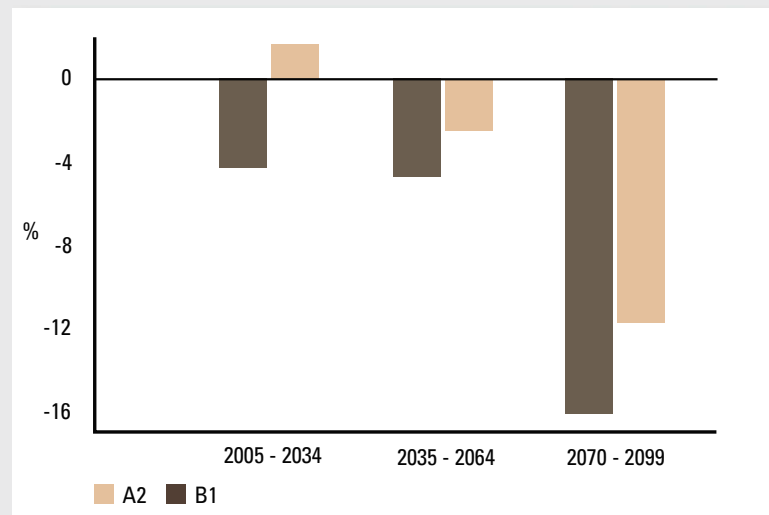
### Water Year (October - September) Precipitation



Precipitation for South Coast (upper) and South Interior (lower) regions of Southern California has experienced wide variation from year to year (light bars). 11 year running mean values (heavy lines) illustrate the substantial multi-year variability that has characterized Southern California's historical precipitation. Historical annual (October-September) precipitation. From California Climate Tracker, Western Regional Climate Center

Figure 8

### Los Angeles Precipitation Change from 1961 - 1990



Projected change in annual total precipitation, Los Angeles region, for A2 (beige) and B1 (brown) emission scenarios. Changes are shown for early (2005-2034), middle (2035-2064) and late (2070-2099) epochs of the 21st Century. Values plotted are the median of the change simulated by six different GCMs, relative to each model's historical average precipitation, for the grid point nearest Los Angeles.

In one form or another, many of Southern California's climate concerns radiate from efforts to secure an adequate fresh water supply. The backdrop is that our Southern California precipitation has a classic Mediterranean pattern, wherein most of the annual precipitation falls in the cooler part of the year, between November and March. The climate change simulations indicate that California will retain its cool season Mediterranean pattern because it depends so strongly on the activity of the winter storm track

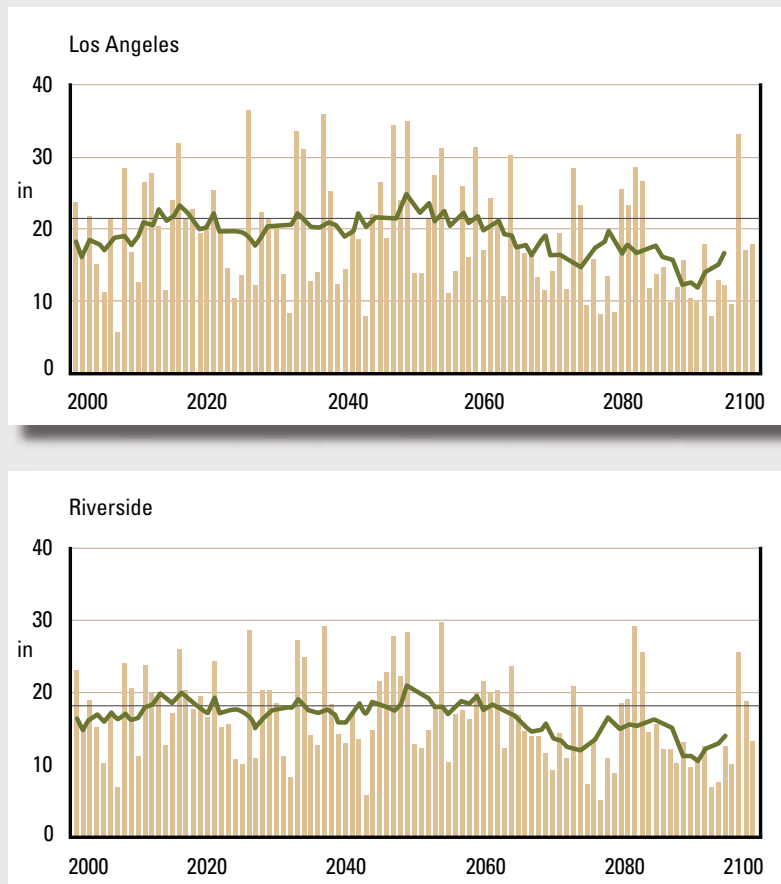
across the North Pacific Ocean. Looking at our historical record, another remarkable feature is the large amount of variability in the delivery of precipitation, not only from month to month but from year to year and decade to decade (Figure 7). Of all the areas of North America, Southern California's annual receipt of precipitation is the most volatile – we only occasionally see a “normal” year, and in the last few we have swung from very wet in 2005 to very dry in 2007 and 2008. Seasonally, we rely almost entirely upon just a few winter Pacific storms to supply the entire year's water budget – in years when some of these storms are weakened or displaced too far north, California falls short. Southern California has special challenges because it is the most urban of the California water user regions and, region-wide, we import more than two thirds of the water that we consume.

Southern California is accustomed to arid conditions, but drought years present exceptional challenges. In many water jurisdictions in Southern California dry spells force greater reliance on imported rather than locally derived water and thus greater demand from large institutional water resources. As climate change produces longer summers and the specter of more frequent drought takes hold, local water supplies may be even leaner. And, because at the same time dryer conditions may also affect the Colorado and Sierra watersheds, the region should prepare for large shortfalls. Climate change looks to have a chance of aggravating that irregularity in that several recent model simulations contain a general decrease in annual precipitation (Figure 8), with some having 30 year deficits of more than 10% below current historical levels (Figure 9). Compounding this drying trend, a warmer climate would likely produce even earlier drying of our landscapes each year, and occasional drought would amplify this. The models also predict drastic declines in the Sierra snowcap by 90%. The result would likely be reductions in streamflow and groundwater recharge that are proportionally even more severe than the reductions in precipitation alone.



Figure 9

### Projected Precipitation



One example of projected future annual total precipitation in Southern California, taken from the GFDL GCM for the A2 greenhouse gas emission scenario. Typical of such simulations, there is considerable precipitation variability from year to year (light bars) and decade to decade (heavy lines, 11 year running mean). As with several (but not all) recent projections, the GFDL simulation contains a trend approaching 25% less precipitation by 2100 than historical levels. Los Angeles (upper) and Riverside (lower) series are derived from a statistical downscaling of the GFDL simulation

The November, 2008 fires in Southern California burned over 40,000 acres and destroyed over 1000 dwellings. This recent flare up, along with the conflagrations of 2003 and 2007, is a reminder that Southern California has some of the riskiest wildfire conditions in the United States. As climate changes, it appears that summer dryness will begin earlier, last longer and become more intense. These changes may exacerbate fire occurrences, which have historically peaked in late summer and early fall. In years with wet winters, annual vegetation growth is plentiful. But accentuated dryness during summer would produce a hazardous fuel load that worsens the wildfire problem in some of Southern California wildlands. With expanding development into the urban/wildland interface, threats to human safety and property are even greater. The spread of invasive species that are more fire-prone, coupled with more frequent and prolonged periods of drought, all increase the risk of fires, and reduce the capacity of native species to recover. Wildfires are also bad news for the region in terms of air quality, human health, soil erosion and stress on watersheds. Direct costs of fighting the 2008 wildfires have been reported at several hundred millions of dollars, and at the time this is written the property damage toll is still being assessed. With climate change we could see more years like this in our future.

Population growth combined with higher temperatures would lead to higher electrical demand. Coastal Southern California being nearly fully developed, new growth is largely slated to inhabit interior valley locations

such as the Inland Empire and the Imperial Valley. California's peak electrical demands in summer are 150% greater than those in winter, to meet air conditioning, water processing and pumping, and other power needs. Even without climate change, this interior development will heighten demand for electricity as needs for summer cooling increase.



Climate warming would further stress the demand for electricity and could increase the likelihood of power outages during the hottest periods. And, complicating this issue, without new sources of “clean” electricity, higher demand would increase greenhouse emissions.

Climate changes are not confined to California – they are taking on a global footprint. In many ways, these extra-regional changes will probably also

affect Southern California. Increased heat waves would intensify the need for electric power throughout California and probably beyond. Nearly 20% of our electrical energy is imported, much of it from hydroelectric generators in the Columbia River basin. The blackouts during California's early Summer 2000 electricity crisis were exacerbated by the lack of hydro-electric power available from the Pacific Northwest. This shortfall was due to dry conditions over the Northwest that had built up over the previous few winters. Recently, a decade of drought in the Colorado River basin and the recent two years of dryness in the Sierra Nevada underscore the frailty of our water supply in Southern California. Recent decisions have tightened the amount of Colorado River water available to California. Water supplies on the Colorado have become nearly fully utilized – it appears that we will have to increase efficiency to muster supplies for new users.

In the foreseeable future, Southern California expects continued growth in population, demand for energy and water, many more vehicles and miles traveled, and shifts in land use and ecosystems. Even in the best of circumstances, climate change will compound many of the problems associated with these developments. The early signs of climate change have already been recorded and considerably more change is on the way. How much more will be determined, to a large extent, by our collective global decisions and policies with respect to fossil fuel use and environmental protection. Climate warming, sea level rise, ecosystem collapses and other shifts are likely not reversible, at least on human generational time scales. So, we cannot afford to wait--taking steps now to limit greenhouse gas emissions to a lower rather than higher pathway could avoid the high end of climate warming. Keeping warming to lower levels will help to reduce “dangerous” consequences and “climate surprises” – reactions that we do not understand well now but that are more likely as the global and regional

climate migrates away from its natural equilibrium. California policy and technological developments are well-noticed by the world community, so that even though climate solutions here are only a small fraction of those needed over a global scale, the way we deal with them can be a model that would be applied elsewhere.

### Acknowledgments

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### About the Author

Dan Cayan, Ph.D., is a Researcher at the Scripps Institution of Oceanography, University of California, San Diego, and also with the U.S. Geological Survey, Water Resources Discipline. He directs the California Climate Change Center and the California Applications Program, multi-institution research programs to provide climate information to the State and region. Dr. Cayan was a lead researcher in the 2005-2006 California Climate Change Scenarios Assessment Project and continues to play that role in the ongoing 2008-2009 California Climate Change Assessment. He was one of the Guest Editors and a science contributor of the Special Issue on “*California at a Crossroads: Climate Change Science Informing Policy*”, *Climatic Change Journal*, March 2008.

### Additional Resources

Announcement of California’s 2008 Climate Change Impacts Assessment  
[http://www.climatechange.ca.gov/research/2008\\_assessment/index.html](http://www.climatechange.ca.gov/research/2008_assessment/index.html)

Our Changing Climate, Assessing the Risks in California  
[http://meteora.ucsd.edu/cap/pdffiles/CA\\_climate\\_Scenarios.pdf](http://meteora.ucsd.edu/cap/pdffiles/CA_climate_Scenarios.pdf)

Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments  
<http://cses.washington.edu/db/pdf/snoveretalgb574.pdf>

IPCC, 2007: Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report.  
<http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf>

California Department of Water Resources, California Water Plan 2006:

<http://www.waterplan.water.ca.gov/>

California Assembly Bill 32 (AB 32): Global Warming Solutions Act

<http://www.ef.org/documents/AB-32-fact-sheet.pdf>

EXECUTIVE ORDER S-13-08 by the Governor of the State  
of California (Sea Level Rise)

<http://gov.ca.gov/executive-order/11036/>

San Diego's Changing Climate, a Regional Wake Up Call

[http://www.sdfoundation.org/news/pdf/Focus2050\\_whitepaper\\_final.pdf](http://www.sdfoundation.org/news/pdf/Focus2050_whitepaper_final.pdf)

The Encyclopedia of Earth: Biological Diversity in the California  
Floristic Province

[http://www.eoearth.org/article/Biological\\_diversity\\_in\\_the\\_California\\_Floristic\\_Province](http://www.eoearth.org/article/Biological_diversity_in_the_California_Floristic_Province)